IONIZATION OF HELIUM BY POTASSIUM POSITIVE IONS

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Abstract

A continuation of previous attempts to ionize gases by positive ions has been extended to helium using potassium positive ions as high as 750 volts accelerating potential. At pressures between 0.01 and 0.1 mm there is definite evidence of ionization of helium above 150 or 200 volts accelerating potential. The effect is much smaller than in the gases previously reported, but it may be distinguished from the secondary emission of electrons from the metal parts under action of the positive ions. Great difficulty was encountered in changes of intensity of ionization due to impurities in the helium. Some of the uncertainties in previous work have been removed by changing the relative positions of electrodes.

IN A previous paper by one of us[1] evidence was offered for the ionization of argon and neon by potassium positive ions. It was determined that these positive ions could produce ionization which was distinguishable from other effects produced upon the metals in the tube when the accelerating potential was in excess of 150 volts. An inherited error in calibration of the McLeod gauge used for pressure measurement caused a misstatement in that paper regarding the pressure range over which the effect of ionization is found. The pressure range is nearer 0.005 to 0.1 mm which partially obviates the argument concerning unusually long mean free paths of the positive ions. The indication is that their paths are comparable with, but slightly longer than, the mean free path calculated from kinetic theory data.

This work has been extended to the study of helium in a new tube using electrical connections practically the same as previously described. Fig. 1 shows the tube with its electrical connections. The chief features in which it differs from the previous tube are (1) a ground glass joint by which filament changes may be more easily effected, (2) greater space between collector S and grid G from which the products of ionization are collected, (3) a flat plate P placed only 2 mm above the grid G and parallel to it. The ground glass joint is made in two parts, the upper part being coated with graphite, the lower portion coated with stopcock grease and sealed with mercury. A vacuum connection between these two parts minimizes the danger of stopcock grease entering the tube. The filament and cathode leads are mounted in this joint so that the filament may be easily removed and recoated with Kunsman catalyst. The cathode is, as before, a steel cylinder completely enclosing the filament; however, the channel through which the positive ions emerge into the upper part of the tube has been made smaller (1.5 mm diameter) and the hole in the collector through which it projects has been

[1] R. M. Sutton, Phys. Rev. **33**, 364 (1929).

made smaller (3 mm diameter) so that the field between collector and grid is more uniform. By placing the grid 2.5 :m above the collector S, a larger region is available from which to collect the products of ionization. Furthermore, the region above the grid is greatl reduced from the previous case so that the amount of ionization produced between the grid and upper plate has a negligible effect upon the plate current (I_p) of positive ions. It was found that the reflection of positive ions from the plate was extremely small or negligible so that the V-shaped plate previously used to reduce reflection was eliminated.

The helium used was obtained in moderately pure form from the United States Bureau of Mines at Amarillo, Texas. It was further purified by passing over oxided copper turnings and charcoal in liquid air until it was spectroscopically pure. As an additional precaution, the helium was passed through

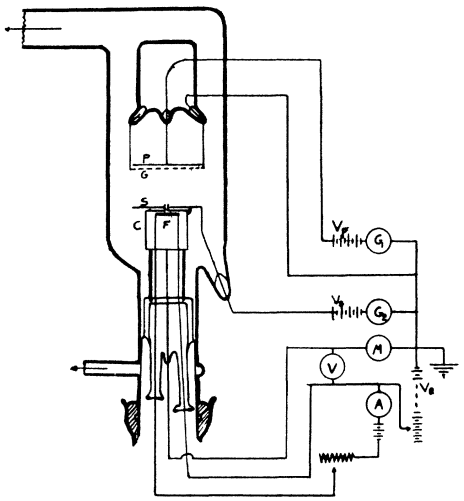

Fig. 1. Experimental tube and connections.

a magnesium discharge tube before its introduction into the experimental tube. The ionization properties of the gas seem to be particularly sensitive to impurities, increasing very materially with amounts of impurity which must be only a few percent of the total gas pressure. It is desired to study this aspect of the ionization more carefully in the future under controlled conditions. Until now, however, the effort has been to work with the purest gas obtainable. Consequently, whenever the gas gave indication of contamination by reason of marked increase of ionization without measurable change of pressure, it was rejected and fresh gas was admitted to the apparatus. This increase may be due in part to ionization of impurities by collision with helium excited by positive ion bombardment.[2]

The system of measurement consisted in directing the potassium positives through the narrow channel in the cathode into the region between the col-

[2] G. P. Harnwell, Phys. Rev. **29**, 683 (1927).

lector S and plate P. The potential of S was maintained 20 volts positive with respect to the cathode (ground) thus preventing positive ions from reaching the collector directly. Any electrons liberated from the grid or from the cathode under impact of the positive ions would reach S in case they had such initial direction as to enter the field of this collecting potential V_s. It was found that the long narrow channel used in these experiments was the source of a rather large amount of secondary emission of electrons to the collector, especially when the channel was contaminated with potassium from the filament. The secondary emission was, in general, about three times as great as it was in the previous tube. Any electrons liberated by ionization of the gas between S and G are collected on S and show themselves as an additional current in excess of the secondary emission. The primary positive current is measured on the plated P, which is also kept positive (18 volts) to prevent the escape of secondary electrons from the plate into the region between S and G. It will be seen that nei-

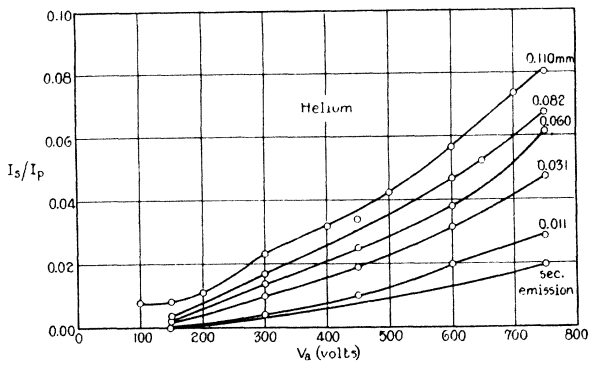

Fig. 2. Ionization in helium at various pressures. Ratio of electron current to collector to positive ion current to plate as function of accelerating potential of positive ions.

ther of these collecting potentials can give electrons energy sufficient to ionize helium and by making the plate potential $V_p = 18$ volts, it was possible to prevent escape of electrons from the plate due to photoelectric effect from radiation produced by excited helium atoms. However, these collecting voltages which are higher than those used in previous work with gases of lower ionizing potentials are in excess of the ionizing potentials of most gases except helium; hence they may be a source of ionization by electrons when impurities are present.

In general, the current to the collector S was measured with a gas pressure of less than 10^{-5} mm and then, without changing other conditions, it was again measured with helium present. A series of measurements of the current to S at different accelerating potentials was made at each gas pressure used, and fresh helium was introduced for each new pressure test. Figure 2 shows a series of curves obtained at various pressures by plotting the electron current to the collector (I_s) divided by the positive ion current to the plate (I_p) as a

function of the accelerating potential of the positive ions. Each curve thus represents the efficiency of ionization at various accelerating potentials for each pressure shown (after subtraction of the current due to secondary emission). The lowest curve was taken with pressure 10^{-5} mm or less. It represents the effect of secondary emission alone. The lowest pressure at which a distinguishable effect due to the presence of helium can be detected is 0.01 mm at which the mean free path of K^+ in helium is approximately one-half the distance between the collector and grid. From .01 to 0.1 mm there is definite evidence of ionization. It will be seen from Fig. 2 that the ionization current plus the secondary emission at 0.11 mm amounts to 8 percent of the initial positive ion stream at 750 volts, and the secondary emission with no gas present is equivalent to approximately 2 percent of this current, which leaves 6 percent as the part due to ionization of the gas assuming that the secondary emission is independent of gas pressure. (This assumption may need some modification inasmuch as the secondary emission in the cathode channel may increase due to scattering of the initial positive beam against the metal). We have no way of determining at present how many impacts each positive ion makes between the collector and grid, so that we are not free to predict or calculate the probability of an impact resulting in ionization. However, it appears to be rather small considering that the positive ions at 750 volts have many times the kinetic energy necessary to ionize helium.

There has been some question as to whether the nature of the discharge through the channel into the upper region of the tube does not change materially with the presence of gas in the tube. This point has been tested by measuring the total current between the cathode and filament under all operating conditions of the tube; the only change in this current due to increase of accelerating potential of the positive ions is such as may be adequately accounted for by the increased secondary emission from the cathode itself under action of the ions up to the potential at which an arc occurs. It is possible, however, that a few positive ions of helium might be formed within this region due to electron impact, and these may emerge into the upper region of the tube to cause collisions with the gas present. It is doubtful whether any such collisions would result in ionization, since the escape of an electron from the combined attraction of two positive helium ions cannot be effected as easily as the escape from the field of a K^+ and an He^+ ion. The chief effect of such helium positive ions in the original beam would be to increase I_p, whereas a decrease in I_p is noted with the presence of the gas. This decrease of I_p upon the introduction of gas may be attributed to a slight cooling of the filament due to conduction, or to retardation of the ions by collision with gas molecules sufficient to prevent their reaching P against the retarding potential of V_p of 18 volts. That part of the decrease of I_p due to stoppage of the initial positive ions obviously causes an abnormally large calculated ratio I_s/I_p. This is particularly evident in the curve for 0.11 mm which does not approach zero as rapidly as do the curves taken at lower pressures. The relatively high ratio at 150 volts is due to almost complete stoppage of the initial positive beam, rather than to a greater amount of ionization at this pressure.

A comparison of results obtained from the present tube with those previously reported was made in a test run on neon. Taking due account of the change of position of electrodes and the increased secondary emission in the present tube, the two tubes give quantitative results in good agreement. Figure 3 summarizes the evidence for argon, neon, and helium. N is the number of electrons per initial positive ion per cm path at 1 mm pressure, calculated at the average of the pressure range, 0.05 mm.[3] The increase of N with pressure indicates the possibility of ionization of more than one gas atom

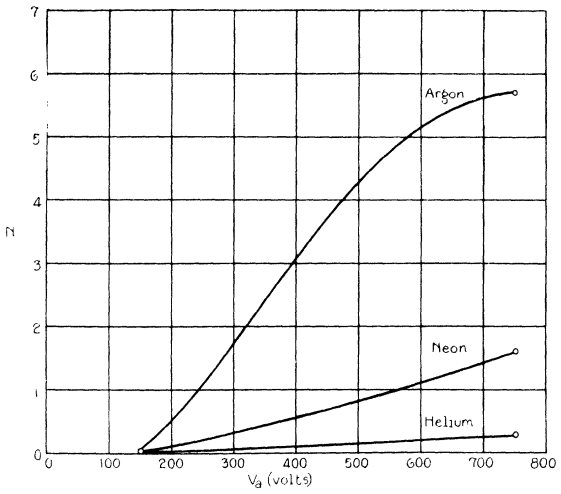

Fig. 3. Comparative ionization of argon, neon, and helium by potassium positive ions. N represents the number of ions formed per positive ion per cm path at 1 mm pressure.

by a single positive. At 0.1 mm pressure each positive ion encounters approximately 15 collisions over a path 3.4 cm long on kinetic theory data. This penetration of the positives is not as great as that previously adduced, due to correction of the pressure measurements, but is still comparable with the magnetic analysis experiments of Durbin, Kennard, and Dempster.[4]

The present work will be continued on the investigation of other gases and different positive ion sources. It seems desirable also to test further the effect of impurities upon ionization of the noble gases.

[3] K. T. Compton and C. C. Van Voorhis, Phys. Rev. **26,** 436 (1925).

[4] F. M. Durbin, Phys. Rev. **30,** 844 (1927); R. B. Kennard, **31,** 423 (1928); A. J. Dempster **31,** 634 (1928).